

Air Quality in Louisville: Past, Present, and Future

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Abstract

Air quality in metropolitan Louisville, Kentucky has improved dramatically over the past thirty years. Upon achievement of compliance with federal standards for carbon monoxide (CO) in 1990 and for ozone (O₃) in 2001, the metropolitan area now meets all current National Ambient Air Quality Standards (NAAQS). Growing knowledge of the health risks posed by air pollutants has led the US Environmental Protection Agency (EPA) to issue stricter standards for O₃ and fine particulate matter, however. These standards will likely take effect by 2004. EPA will likely also tighten standards for hazardous air pollutants (HAPs), organic chemicals that increase risks for cancer, birth defects, or other serious illnesses. The region will need continuing improvements in air quality to meet these new standards. This paper presents a historical overview of air quality in metropolitan Louisville, anticipated challenges over the next several years, and promising methods for meeting these challenges.

Air Quality in Louisville: A Historical Summary

Pre-Industrial Conditions

Various activities have introduced harmful substances into the air throughout history. The use of fire for cooking, heating, or to control plants or animals, releases carbon monoxide (CO), particulates, volatile organic compounds (VOCs), and nitrogen oxides (NO_x). Ground-disturbing activities such as agricultural tilling, clearing paths or roads, and building structures result in airborne dust. Natural events such as volcanic eruptions, wildfires, lightning, and windstorms contribute large quantities of pollutants. Several pollutants can remain in the atmosphere long after their emission and travel far from points of origin. Particulates from forest fires and volcanoes thousands of miles away probably affected air quality in the Ohio River valley many times before anthropogenic pollutants significantly altered air chemistry. Evidence suggests, though, that pre-industrial air would have met modern air quality standards readily except during episodes involving fires, volcanic eruptions, or dust storms.

The Era of Coal

Emissions from coal-fired residential furnaces, industrial boilers, and steam locomotives caused enormous atmospheric particulate loads, which in turn blanketed Louisville and other industrialized cities with thick haze. In the late 1940s, the Louisville Smoke Commission (predecessor of the Air Pollution Control District) monitored atmospheric particulates by suspending buckets on lampposts and weighing the collected soot! Coal-

and wood-burning also resulted in high levels of invisible but harmful pollutants, including carbon monoxide (CO), nitrogen dioxide (NO₂), and sulfur dioxide (SO₂).

The Dawn of Air Quality Regulations

“Killer fogs” that enveloped Meuse Valley, Belgium in 1930 (killing 60 and causing thousands of illnesses), Donora, Pennsylvania in 1948 (killing 21 and sickening over 6000), and London, England in 1952 (killing 4000) brought to public awareness the potential deadliness of air pollution. In each of these instances, industrial pollutants trapped by a thermal inversion during a period of stagnant winds resulted in acutely toxic air and near-zero visibility. A combination of SO₂ and fine particulates most likely caused the deaths and illnesses. In the wake of these tragedies, many governments enacted air quality standards.

From January 1956 through May 1957, the Special Air Pollution Study of Louisville and Jefferson County, Kentucky gathered data that greatly expanded the understanding of the quantity, composition, and sources of air pollutants in western Jefferson County. According to the study’s report, “It didn’t require a catastrophe like the Donora, Pennsylvania, smog of 1948 to make the people of Louisville and Jefferson County aware that something should be done about air pollution. There were no overwhelming incidents, but the citizens were conscious of the ever-increasing burden of fumes, odors, and dusts that were in the air.”

Despite this nod to Donora, the study focused on the nuisance aspects of air pollution: dust settling on clothing, windows, etc.; eye and lung irritation (presumed to have no lasting consequences); unpleasant odors; and haze. The health effects of extended exposure to pollutants at well below their acutely toxic levels had not gained scientific or public recognition. Although the toxicity of CO was well established, the study explicitly ignored it as a pollutant, presumably because it has no odor or opacity and causes no tissue irritation. Because of differences in measurement methods between this study and modern EPA standard methods, one cannot precisely correlate the study’s results with more recent measurements. The study’s results suggest, however, that Louisville in 1956-1957 significantly exceeded modern standards for particulates and SO₂. High reported levels of NO₂ and VOCs (the principal precursors to the formation of ground-level O₃) indicate a strong possibility of high peak O₃ concentrations as well.

The Special Air Pollution Study concluded with recommendations for improving the region’s air quality. The authors called for control of the most egregious sources of airborne particulates from combustion and industrial processes, control of SO₂ by using coal of lower sulfur content, emission limits on industrial odorant gases, and installation of vapor control devices to reduce evaporation of fuels. These recommendations aimed to curtail the palpable inconveniences of air pollutants rather than to mitigate their long-term health effects.

From 1959 through the 1960s, the Air Pollution Control District of Jefferson County (APCD) enforced a relatively simple set of regulations that essentially embodied the recommendations of the Special Air Pollution Study. These regulations dealt largely with the proper construction and operation of industrial boilers and other combustion equipment. The regulations capped dust or fly ash emissions from industrial stacks at 850 ppm (by weight of flue gas), or at 400 ppm for steam plants with capacities above 200,000 pounds of steam per hour. For industrial process dust, the rules limited effluents to 850 ppm (by weight) of dust above 10 micrometers in particle size, with no more than 200 ppm constituting particles larger than about 45 micrometers (number 325 mesh). Vehicular and industrial stack emissions of smoke were regulated according to opacity, estimated visually. The regulations called for vapor suppression or vapor recovery devices to reduce evaporative hydrocarbon emissions from fuel and petroleum distillate tanks with capacities of over 40,000 gallons. The regulations did not require any monitoring or control of gaseous pollutants such as SO₂, NO₂, or CO.

The Darkest Hour (circa 1970)

Despite pioneering air quality regulations such as these, air pollution probably increased in much of the United States during the 1950s and 1960s. (The absence of comprehensive air monitoring data prior to 1972 prevents precise comparisons.) Population growth, rapid industrial growth, increasing household electricity use, and steeply growing automotive travel led to increasing emissions of pollutants.

The 1962 publication of *Silent Spring* by Rachel Carson ushered in the modern era of concern for environmental quality. In addition to building support for the creation in 1970 of the US Environmental Protection Agency (EPA), Carson's book convinced the public that odorless, invisible contaminants could cause disease and death in humans, other animals, and plants. Effective environmental protection would require control of substances present at below the thresholds of human smell, vision, taste, and touch.

The federal Clean Air Act Amendments of 1970 required the EPA to establish National Ambient Air Quality Standards (NAAQS). EPA identified and set criteria for six air pollutants: sulfur oxides (SO_x), nitrogen oxides (NO_x), CO, total suspended particulate matter, hydrocarbons, and photochemical oxidants. These standards marked a major departure in regulatory policy in that they required measurement of ambient concentrations of pollutants in addition to measurement of emissions from large stationary sources. Further, they dealt almost entirely with substances not previously monitored routinely by industry or government. The NAAQS required the development of new emission control methods and equipment for factories, power plants, and motor vehicles and the development of new systems to monitor compliance. By establishing for each pollutant a primary standard to protect human health and a secondary standard to protect economic and ecological resources, the EPA acknowledged the importance of the wide range of effects of each pollutant.

The sweeping changes set in motion by the Clean Air Act took several years to implement and to improve air quality. In 1975, APCD's network of eight monitors in Jefferson County recorded its historic peak of 68 exceedances of the federal CO standard

(an 8-hour average reading of 9 ppm or higher in ambient air), with 8-hour averages up to 22.8 ppm. The region's ground-level (tropospheric) O₃ concentrations generally increased through the 1970s before beginning a downward trend. The peak ozone reading reached 0.275 ppm in 1975, over twice the federal ceiling. Metropolitan Louisville's ambient air concentrations of the EPA-designated "criteria pollutants" excepting SO_x probably all peaked in the 1970s. (SO_x levels had probably already declined significantly due to implementation of the 1959 Louisville regulations.)

Progress Since the 1970 Clean Air Act Amendments

National Ambient Air Quality Standards (NAAQS) Defined

The National Ambient Air Quality Standards (NAAQS) set by EPA must account for temporal and spatial variations in pollutant concentrations as well as the possibility of a brief period of erroneous or unrepresentative readings at a given monitor. APCD operates a network of monitors to record ambient concentrations of the six criteria pollutants in Jefferson County. The Indiana Department of Environmental Management and Kentucky Department for Environmental Protection operate other monitors in the metropolitan area. EPA regulates measurement methods, sampling periods, statistical methods, and manner of reporting. To provide a conservative reflection of the worst pollution exposure within a monitoring region, EPA defines a "design value" for each criteria pollutant.

Ozone (O₃), currently the greatest compliance challenge, presents a good example. O₃ monitors record one-hour averages. The design value for a given monitor is the fourth-highest daily peak one-hour reading recorded during the past three ozone seasons (from March 1 through October 31 each year). Table 1 demonstrates the determination of the one-hour O₃ design value for 1999-2001 for two monitoring sites in the APCD network. The four highest daily peak one-hour readings recorded at the monitor in Charlestown, IN from 1999-2001 ranged from 0.106 ppm (on 7/27/1999 at 6 PM and 6/13/2001 at 3 PM) to 0.112 ppm (on 7/30/1999 at noon). Thus, for 1999-2001, the Charlestown, IN monitor had a design value of 0.106 ppm. For a network of monitoring sites, the design value constitutes the highest design value for the sites in the network. The two-site "network" in the example of Table 1 thus has a design value of 0.115 ppm.

For greater Louisville for 1998-2000, the Charlestown monitor had the highest O₃ design value (0.124 ppm) among the seven sites in the network. This gave the metropolitan Louisville air quality planning area a one-hour O₃ design value of 0.124 ppm for 1998-2000, narrowly in compliance with the NAAQS of 0.12 ppm (rounded to two decimal places, per EPA practice). As shown in Figure 1, reducing ambient ozone levels to meet the federal standard was a great achievement.

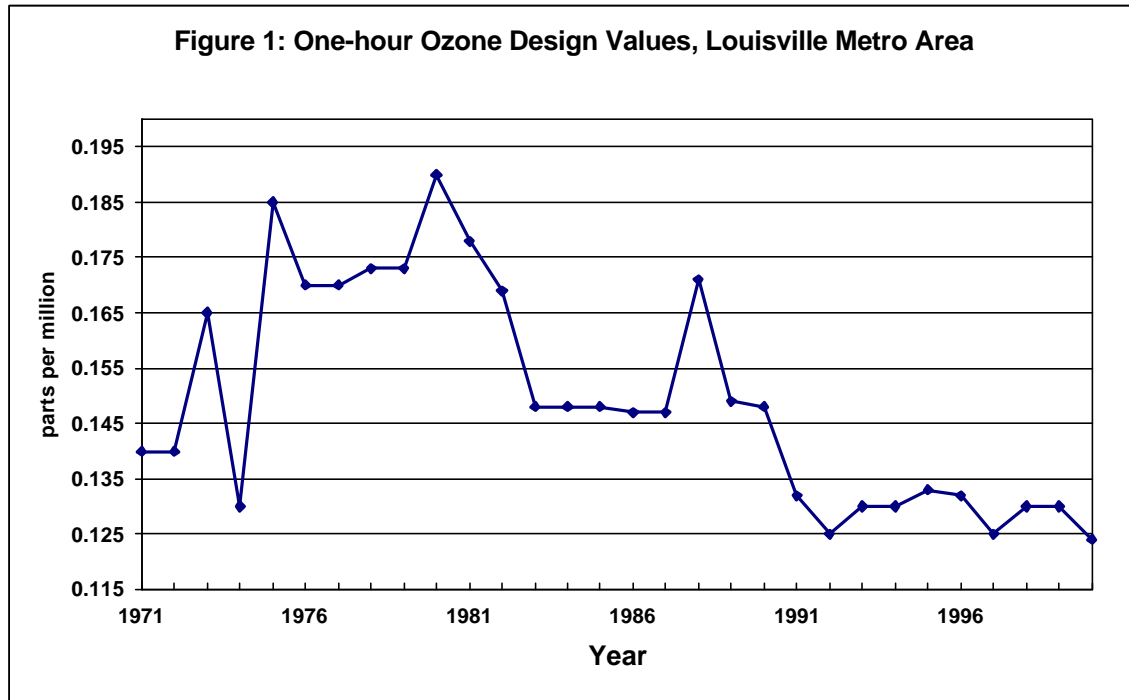
Table 1: Example calculation of one-hour ozone design value.

	2001			2000			1999			Design Value		
<u>Site</u>	<u>ppm</u>	<u>Date</u>	<u>Hour</u>	<u>ppm</u>	<u>Date</u>	<u>Hour</u>	<u>ppm</u>	<u>Date</u>	<u>Hour</u>	<u>ppm</u>	<u>Date</u>	<u>Hour</u>
Charlestown	0.109	5/5	3 pm	0.105	8/17	3 pm	0.112	7/30	Noon	0.106	6/13/01	3 pm
	0.106	6/13	3 pm	0.101	6/1	2 pm	0.107	8/16	5 pm			
	0.101	6/19	5 pm	0.101	8/15	18	0.106	7/27	6 pm			
	0.101	8/1	3 pm	0.097	7/27	14	0.103	6/22	1 pm			
New Albany	0.107	8/1	3 pm	0.101	8/17	3 pm	0.120	6/10	1 pm	0.115	7/30/99	6 pm
	0.096	8/7	4 pm	0.093	6/4	17	0.120	6/22	3 pm			
	0.088	6/18	5 pm	0.092	8/14	3 pm	0.116	7/8	4 pm			
	0.087	8/2	1 pm	0.092	8/15	17	0.115	7/30	6 pm			
Both sites:										0.115		

Notes:

ppm = one-hour ozone reading, parts per million. Each reading occurred at the date and time shown.

Values in **boldface** represent the four highest readings at the given site during 1999-2001.



Progress on criteria pollutants

The standards set by EPA pursuant to the Clean Air Act Amendments of 1970, 1977, and 1990 required many changes in pollution-generating activities. New requirements have included emission controls on motor vehicles, power plants, and industrial processes; continuous emissions monitoring on many industrial facilities; changes in the compositions of motor fuels and industrial fuels; and replacement or refurbishing of some high-emission equipment. Local and state environmental agencies enforce many of the federal standards, and promulgate and enforce additional regulations to improve their regions' air quality. Important steps by Jefferson County to meet the NAAQS have included:

- motor vehicle inspection and maintenance (I/M) or “vehicle emissions test” (VET) program [reduces CO, VOCs, and NO_x], 1984
- gasoline vapor recovery at fueling stations [reduces VOCs], 1993
- reformulated gasoline (RFG) [reduces CO, VOCs, NO_x, and hazardous air pollutants], 1995

The Clean Air Act Amendments of 1977 directed the EPA to review at five-year intervals the list of criteria pollutants and the NAAQS for each. Of the initial six criteria pollutants, only CO remains on the list. EPA established a NAAQS for lead (Pb) in 1978. Subsequent revisions to the list of criteria pollutants deleted hydrocarbons, substituted ozone for photochemical oxidants, substituted NO₂ for NO_x, substituted SO₂ for SO_x, and substituted particulate matter smaller than 10 micrometers (PM₁₀) for total suspended

particulates. Only for O₃ (and its superset, photochemical oxidants) and CO has Metropolitan Louisville ever exceeded a NAAQS.

As noted above, Louisville's CO problems reached their peak in 1975, with 68 reported exceedances and two readings that more than doubled the applicable standard. From 1975 to 1985, the number of annual exceedances of the federal CO standard registered at APCD monitors dropped from 68 to one. Three exceedances occurred over the next eight years. Since 1993, no monitoring site in the Louisville metropolitan area has registered an exceedance of the CO standard. On 16 April 1990, the EPA recognized that Jefferson County had come into compliance with the NAAQS for CO (*Federal Register* vol. **55**, no. 73, p. 14092-3). Much of the drop in CO probably stemmed from implementation of federal controls on motor vehicle exhaust. Maintaining compliance over the past eleven years in spite of increased motor vehicle use has resulted from continued improvements in motor vehicles as well as from the institution of the vehicle I/M, gasoline vapor recovery, and RFG programs.

Ozone, the principle photochemical oxidant formed in "smog," arises from atmospheric reactions of NO_x and VOCs in the presence of solar ultraviolet radiation. CO, hydroxyl (OH) ion, water vapor, and other atmospheric chemicals also play roles in the reactions, which progress more rapidly at higher temperatures. High vehicular and industrial emissions of VOCs and high vehicular and utility emissions of NO_x result in high ambient O₃ concentrations on hot, sunny days with light winds. Excursions over the federal standard of 0.12 ppm occurred nearly every summer in Louisville until 1998, often several times per season. (EPA raised the 1-hour NAAQS from 0.08 ppm of total photochemical oxidants to 0.12 ppm O₃ in 1983, relaxing the standard by over 50%.) Because O₃ forms in the atmosphere rather than appearing directly from emission sources, its control is indirect via control of its precursors. Several uncertainties regarding emission rates of biogenic VOCs (primarily from trees) and the aggregate photochemical reactivity of locally present anthropogenic VOCs further complicate understanding of how control measures influence ambient O₃ levels.

Nonetheless, federal, state, and local control strategies appear to work. Whether measured in terms of annual peak one-hour reading, design value, or hours per year above the NAAQS, metropolitan Louisville's O₃ levels have dropped considerably. In 1975 and 1980, O₃ reached the "serious" level as defined by EPA. In 1980, the peak recorded in Jefferson County reached 0.197 ppm, and 62 hours during 28 days had readings above the 0.12 ppm NAAQS. By contrast, during 1999-2001 no monitor in Jefferson County recorded a reading above 0.12 ppm. Even during the historically hot summer of 1998, only four excursions above 0.12 ppm were recorded in Jefferson County, with a peak reading of 0.132 ppm.

Emissions inventories estimate total emissions from point sources (large industrial and utility facilities), mobile sources (motor vehicles and portable equipment), and area sources (small and dispersed sources such as dry cleaners, automobile body shops, and household fireplace use). While most industrial sources provide accurate emissions data via continuous monitoring devices, quantifying emissions from mobile and area sources is much more time-consuming and approximate. Using EPA-approved methods, APCD

has compiled complete emissions inventories for NO_x, VOCs, and CO every three years since 1990. The inventories cover Jefferson County and its O₃ “maintenance area” (formerly its “nonattainment area”) including Clark and Floyd Counties in Indiana and portions of Bullitt and Oldham Counties in Kentucky.

According to APCD’s estimates, VOC emissions dropped by half from 1990 to 1999 in Jefferson County but stayed roughly constant in nearby areas. Emission reductions came from improved manufacturing practices, improved motor vehicle technology, more stringent vehicle emissions testing, reformulated gasoline, and reduction in household and commercial use of solvents and oil-based paints. These reductions were partially offset by increased use of high-emission non-road vehicles and equipment such as diesel-powered construction equipment and gasoline-powered landscaping tools.

Regional NO_x emissions showed no clear trend from 1990 to 1999. An 82% increase in motor vehicle emissions offset a 21% decrease in point source emissions. The rise in motor vehicle emissions arose from increased private automobile use without significant advances in motor vehicle NO_x control.

Regional CO emissions dropped by about 39% over the period due to a drop of nearly 52% in emissions from motor vehicles, the predominant source of CO. Improved vehicle technology coupled with the vehicle I/M program and reformulated gasoline with oxygenates led to these improvements. Non-road mobile source emissions of CO nearly doubled, however. In the 1999 inventory, motor vehicles accounted for 74% of CO emissions (down from 93% in 1990), while non-road mobile sources accounted for 22% (up from 5% in 1990).

As noted above, the Louisville region has met the NAAQS for all criteria pollutants other than CO and O₃ since the inception of the standards. Ambient concentrations of CO, PM₁₀, Pb, NO₂, and SO₂ have all dropped over the past thirty years, to levels generally less than half of the allowable maxima.

Air Quality in Louisville: Current Conditions

Criteria Pollutants

As described earlier, the Louisville area meets all current NAAQS. Four concerns require continued vigilance regarding criteria pollutants, however:

- the potential for sporadic and localized exceedances of the O₃ and CO standards;
- the contributions of local pollutants, particularly NO_x and SO₂, to environmental problems elsewhere;
- the potential for further improvement of local public health by reducing pollutants to well below maximum allowable values; and
- the implementation of more stringent federal standards, particularly for O₃ and particulates, over the next several years.

Small areas of high CO concentration, known as CO “hot spots” can form at congested road intersections with slow or stalled traffic, and in “urban canyons” created by tall buildings lining the roads. High CO concentrations can cause headaches, dizziness, and slowed reflexes in drivers, pedestrians, and bicyclists traveling through hot spots. Highly localized and subject to dispersion by wind or traffic movement, a hot spot may show unacceptable CO levels at a point on the edge of the road and tolerable CO levels ten feet away. APCD uses a micro-scale model to predict potential CO hot spots at congested intersections during periods of peak traffic coinciding with calm winds. APCD has placed CO monitors at some predicted hot spot locations to provide continuous data from likely worst-case sites. APCD routinely models proposed new intersections and proposed large development sites to assess potential CO impacts. Approval of any proposed development rests in part on a determination that the new land use would not generate a CO hot spot by virtue of causing traffic congestion. Typically, changing the intersection or site design slightly (e.g., by adding another access/egress point or adding a preferential turn lane) will alleviate the CO concern by reducing the peak traffic congestion.

While metropolitan Louisville continues to experience a clear downward trend in ground-level O₃, one cannot safely presume that the area will not again see readings above the NAAQS of 0.12 ppm averaged over one hour. Very hot and clear weather coupled with inopportune excursions in NO_x or VOC levels might well result in O₃ peaks above 0.12 ppm. Unusual peaks in NO_x or VOC levels can arise from forest fires, chemical spills, or industrial accidents, among other causes. Local O₃ levels reflect NO_x from both local and distant sources, as NO_x can drift for hundreds of miles before its consumption in atmospheric reactions. Continued compliance with the 1-hour O₃ standard will require continued reduction of local emissions of O₃ precursors, to allow for spikes from uncontrolled sources.

Although greater Louisville has kept levels of SO₂ and NO₂ at less than half of the respective NAAQS, the locally generated SO₂ and NO₂ contribute to air and water pollution downwind. NO₂ emitted in the southern and Midwestern US contribute to tropospheric O₃ formation on the eastern seaboard. Acid deposition in rural lakes, streams, and forests results from NO₂ and SO₂ transported from urbanized and industrialized areas including those in the Midwest. The federal “NO_x SIP Call” of 1998 required 22 Midwestern and Southern states and the District of Columbia to develop state implementation plans (SIPs) to limit their emissions of NO_x and thereby facilitate O₃ compliance by urban areas to their east. The federal Acid Deposition Program established by Title IV of the Clean Air Act Amendments of 1990 calls for large permanent reductions of NO_x and SO₂, primarily by reducing emissions from coal-fired power plants.

APCD generally relies on EPA to set appropriate health-based ambient air quality standards. While not currently pursuing stricter local standards, APCD encourages institutions and individuals to reduce harmful emissions whenever possible through cost-effective voluntary measures. EPA sets the primary NAAQS to protect public health. Advances in knowledge of the health effects of air pollutants require periodic revision of the standards. Maintaining ambient pollutant levels below the federal standards may

prove to have improved public health when subsequent research justifies tighter standards.

Epidemiological evidence led EPA in 1997 to promulgate stricter NAAQS for O₃ and a new standard for fine particulates. Achievement of the new O₃ standard, 0.08 ppm averaged over eight hours, will reduce the risks of asthma and other breathing disorders. Continuous monitoring data from sites around the US prove the 0.08 ppm 8-hour standard more stringent than the 0.12 ppm 1-hour standard, which remains in force. The new EPA standard for airborne particulate matter applies to particles and droplets finer than 2.5 micrometers (PM_{2.5}). These fine particulates, which penetrate more deeply into the lungs than do coarser particulates, increase risks for breathing disorders and heart disease. Implementation of both of these new standards awaits resolution of legal challenges. The courts have upheld EPA's authority to promulgate the standards, but have remanded to the agency the schedule and other details of their implementation. Although greater Louisville complies with the PM₁₀ and 1-hour O₃ standards, data from the past three years indicate the need for further air quality improvements to meet the PM_{2.5} and 8-hour O₃ standards.

Hazardous Air Pollutants

The Clean Air Act Amendments of 1990 established a list of 189 hazardous air pollutants (HAPs or "air toxics") known to act as carcinogens, mutagens, or reproductive toxins or to have other serious health effects. EPA has subsequently revised the list to 188 chemicals. (Seventeen of the 188 are actually families of related chemicals, e.g., coke oven emissions, glycol ethers, and mercury compounds.) EPA began in 1990 to establish maximum achievable control technology (MACT) standards to reduce emissions of each of the HAPs from the many industrial and commercial processes known to emit it. The law requires industrial sources of HAPs to operate using the appropriate MACT within ten years (or 16 years in certain cases) of the standard's enactment. Ten years after instituting each MACT requirement, EPA must review the residual risk posed by the HAP in question. EPA may then promulgate tighter standards if needed to protect public health. Federal standards also require industrial monitoring and reporting of HAPs emissions.

APCD issues permits to sources of HAPs in Jefferson County, and reports to EPA annually the emissions of HAPs from these sources. Of the 188 air toxics, Louisville industries emitted about 53 in any given year since 1994. Of these 53 compounds, 24 were emitted in quantities of over five tons per year in 1994. (Fifteen HAPs had Jefferson County emissions under 200 pounds per year.) For each of these 24 HAPs, five or fewer sources accounted for at least 90% of the emissions. As a result, changes in production rates, manufacturing methods, or emissions controls at a single facility occasionally caused a large change in the County's emission inventory of a particular HAP. Overall HAP emissions in Jefferson County have changed little over the past seven years, although emissions of some individual substances showed a significant trend. Emissions of bis (2-ethylhexyl) phthalate, methylene chloride, and 1,1,1-trichloroethane dropped to zero from 1994 to 2000. Some HAP emissions have increased significantly during the period: 1,3-butadiene, by 210%; ethylbenzene, by 78%; methylisobutyl ketone, by 71%;

and methylmethacrylate, by 48%. Others have decreased: toluene, by 46%; methylethyl ketone, by 42%; formaldehyde, by 37%; styrene, by 31%; and acrylonitrile, by 26%.

Air toxics also arise from mobile sources and area sources. The EPA has identified diesel engine exhaust particulates as a likely human carcinogen in common atmospheric concentrations. Non-road diesel engines running on fuel with sulfur contents up to 3000 ppm add significantly to these toxic emissions. (Diesel fuel manufacturers voluntarily limit highway diesel fuel to a maximum of 500 ppm sulfur.) Gasoline engines, particularly those without catalytic converters, also contribute to air toxics. Dry cleaning establishments in aggregate emit significant quantities of perchloroethylene, a HAP. Similarly, automobile body shops and other small businesses using polymer resins collectively emit significant quantities of organic HAPs.

Greenhouse Gases

“Greenhouse gases” have high transparency to solar radiation (primarily at optical wavelengths of 350-700 nanometers) but absorb or reflect infrared wavelengths (5,000–17,000 nanometers) characteristic of the re-radiation of heat from earth to space. Higher atmospheric concentrations of greenhouse gases heat the earth by increasing the temperature at which the planet’s surface reaches radiative equilibrium with the sun and space. The term “radiative forcing” describes an atmospheric constituent’s tendency to raise (positive radiative forcing) or lower (negative radiative forcing) the planet’s equilibrium temperature. Pre-industrial greenhouse gases including water vapor, carbon dioxide (CO₂), and methane (CH₄) caused radiative forcing that increased earth’s equilibrium temperature from about 5°F (with a hypothetically transparent atmosphere or in a vacuum) to about 60°F. The “global warming potential” of a substance measures its radiative forcing properties, its longevity in the atmosphere, and its tendency to contribute to atmospheric chemical reactions that form other greenhouse gases (e.g., O₃). Due to its abundance, CO₂ constitutes the most important anthropogenic greenhouse gas. Per unit mass, though, CH₄ has a global warming potential 22 times as great as that of CO₂. Various other gases, primarily industrial in origin, have global warming potentials from 100 to 10,000 times that of CO₂ on a mass basis.

During the past 300 years, average atmospheric levels of CO₂ have increased from about 275 parts per million by volume (ppmv) to about 356 ppmv, a 29% rise. During the same period CH₄ has increased from about 0.75 ppmv to about 1.7 ppmv, a 127% rise. Analyses of ancient air samples from arctic ice show the current levels and rates of increase of CO₂ and CH₄ to have no precedent in the past 160,000 years. Fluorocarbons, chlorinated fluorocarbons, and other anthropogenic gases with very high radiative forcing potentials have appeared in the atmosphere only in the past century. The documented rise in greenhouse gas concentrations and mounting evidence of rising global average temperatures over the past century have led to a growing scientific consensus that human activities are contributing to global climate change.

No federal, Kentucky, or Jefferson County regulations currently cover emissions of greenhouse gases, except for those regulated for their other environmental consequences (e.g., carbon tetrachloride and 1,1,1-trichloroethane, both air toxics). Greenhouse gas

control policies generally involve developing a greenhouse gas emissions inventory for a baseline year and pursuing reductions from the baseline emissions. In 1996, University of Louisville professor Hugh Spencer prepared the report, *Kentucky Greenhouse Gas Inventory: Estimated Emissions and Sinks for the Year 1990* for the Kentucky Natural Resources and Environmental Protection Cabinet, Division of Energy. This report, which details all known significant biogenic and anthropogenic greenhouse gas sources and sinks in the state, estimated Jefferson County's 1990 net greenhouse gas emissions at 42,815,000 tons per year of CO₂ equivalent. (One ton/year of CH₄, for example, equals 22 tons/year CO₂ equivalent because CH₄ has a global warming potential 22 times that of CO₂.) This total is by far the highest of the counties in Kentucky, and represents nearly 22% of the state's emissions. Because of the extremely high global warming potentials of chlorinated fluorocarbons (CFCs) and halogenated hydrocarbons (HCFCs), releases of these compounds from three large manufacturing facilities in Jefferson County may account for over 5% of the county's total greenhouse gas emissions. At present, no agency maintains a greenhouse gas emissions inventory for Jefferson County or Kentucky, although a few other states maintain such inventories. Several bills pending before the US Congress call for establishing a national greenhouse gas emissions inventory.

Stratospheric Ozone-Depleting Compounds

Under the Montreal Protocol, adopted by the United Nations Environmental Programme in 1987, signatory nations are phasing out the production and use of substances that damage the stratospheric ozone layer. These include chlorine- and bromine-containing compounds that do not decompose in the lower atmosphere but, upon convective transport into the upper atmosphere, break down from exposure to ultraviolet radiation. The resulting free chlorine or bromine atoms readily react with O₃ and other atmospheric constituents with the net effect of consuming stratospheric O₃. Ozone in the stratosphere (at several times the concentrations that humans would find tolerable at ground level) strongly absorbs solar ultraviolet radiation, thereby providing an effective ultraviolet shield for the biosphere.

Jefferson County houses three of Kentucky's five largest sources of stratospheric ozone-depleting chemicals, DuPont (1,870,000 lbs. in 1999), GE Appliances (434,000 lbs. in 1999), and Louisville Packaging (331,000 lbs. in 1999). Ozone-depleting compounds are also released as "fugitive emissions" from small and widely dispersed sources, e.g., leaks in air-conditioning and refrigeration systems. Due to a 52% drop in DuPont's emissions from 1996 to 1999, and in spite of significant increases in emissions from the other two large sources, Jefferson County experienced a drop of about 39% in emissions of ozone-depleting compounds during that three-year period. Nonetheless, Jefferson County accounts for 49% of Kentucky's total emissions of ozone-depleting chemicals. As of 1999, Kentucky had the highest on-site (industrial) emissions of ozone-depleting chemicals of any state.

Air Quality Challenges Ahead

Tropospheric (Ground-Level) Ozone

Greater Louisville, having reached attainment with the NAAQS for O₃ in 2001, will face a new compliance challenge upon implementation (probably by 2007) of the new 8-hour O₃ standard. The complex and indirect relationships between tropospheric O₃ concentrations and local emissions of O₃ precursors present difficulties in crafting a compliance strategy. The transport of O₃ and its precursors into and out of the region may play a greater role than anticipated in modeling conducted to date. Recent measurements suggest that O₃ and its precursors may circulate in significant quantities even over transcontinental distances. The average rates, diurnal variations, and temperature dependence of biogenic emissions of VOCs remain subject to great uncertainty. These emissions may constitute over 50% of the region's VOC emissions inventory. Neither photochemical modeling nor empirical correlations have progressed far enough to provide reliable predictions of the emissions reductions needed to bring the region into compliance with the 8-hour O₃ standard.

In the face of these uncertainties, metropolitan Louisville will probably seek to meet the 8-hour O₃ standard by means similar to those that reduced the region's O₃ levels over the past twenty years. The replacement of older motor vehicles with models having modern emissions controls and on-board diagnostics, along with the introduction of cleaner drive trains and fuels, will reduce mobile source emissions of VOCs, NO_x, and CO. Continued reductions of NO_x emissions from industries and utilities should result from federal programs designed to reduce acid rain and East Coast O₃ problems. Continuing replacement of solvent-based paints and coatings with water-based substitutes can reduce industrial and area-source emissions of VOCs.

PM_{2.5}

Data collected during the past three years indicate that the region will need to reduce fine particulates by roughly 15% to meet the federal PM_{2.5} standards expected to take effect in the next few years. Data from "speciation" monitors, which determine the chemical composition of the collected particulates, will allow APCD to formulate control strategies on the basis of the predominant chemical species present. Aerosol sulfates and nitrates, two major constituents of PM_{2.5}, form primarily through atmospheric reactions involving SO_x and NO_x, respectively. Fugitive dust consists of fine solid particulates released incidental to manufacturing, agricultural, construction, and other activities. According to the Kentucky Division for Air Quality, fugitive dust makes up over 60% of PM_{2.5} emissions in Kentucky, but it may constitute a smaller fraction of metropolitan Louisville's PM_{2.5} emissions. Measures aimed at reducing SO_x and NO_x will reduce the sulfate and nitrate components of PM_{2.5}. Local control of fugitive dust may involve additional industrial controls as well as measures beyond those already in place to reduce dust arising from construction, demolition, and vehicle use on unpaved surfaces.

Intercontinental transport of fine particulates contributes to observed local peaks in PM_{2.5}. Forest fires in Central America, volcanic eruptions in Asia, and dust storms in North

Africa have caused spikes in PM_{2.5} values in the US, including Louisville. Upon establishing clear correlation between a distant source of particulates and widespread high readings in the US, the EPA may discount the unusually high readings for purposes of establishing compliance with the NAAQS. Nonetheless, these uncontrollable distant events may affect public health in the US.

HAPs

Increasing understanding of the health consequences of HAPs may lead to tighter regulation of specific compounds. EPA plans to limit mercury emissions from coal-fired power plants, the largest sources of atmospheric mercury. EPA has issued standards to reduce sulfur content in highway diesel fuel to 15 ppm by 2006. In addition to direct reductions in sulfur-containing particulates, the cleaner fuel will enable the use of catalytic converters that will dramatically reduce HAPs and NO_x in diesel exhaust.

Haze

Visibility-impairing haze arises principally from particulates and NO₂. Haze worsens in humid weather, when sulfate aerosols and other particles absorb atmospheric moisture and grow in size. The control strategies for PM_{2.5} apply also to regional haze. Due to the long-distance transport of fine particulates, haze seriously affects areas far from the responsible emission sources. National parks and other scenic areas have suffered large losses in visibility because of anthropogenic haze from pollution generated in distant industrialized or urban areas.

Acid Rain

Despite improvements over the past fifteen years, rainfall collected at sites across Kentucky remains more acidic (approximately pH 4.5 on average) than the unimpaired norm of pH 5.0 – 5.6. Studies in other states have shown that lakes and streams have rebounded less quickly from acid rain than regulators had hoped to result from the current regimes of SO₂ and NO_x controls.

Greenhouse Gases

Voluntary measures to curtail greenhouse gas emissions, as described below, offer large potential reductions. The absence of a national greenhouse gas control program, however, reduces the economic incentives available to promote emission reductions.

Avenues for Cleaner Air in Louisville

A variety of regulatory and voluntary methods will likely contribute to air quality improvements over the next twenty years. The causal links between some substances or activities and several air quality problems makes possible harmonized approaches in which one action can benefit air quality in several ways. While targeted efforts to limit the release of a single pollutant from a particular process will continue important, harmonized approaches with multiple benefits will likely yield the largest improvements.

National Initiatives with Local Implications

Federal regulations have largely driven the improvements in air quality noted over the past thirty years. The Clean Air Act Amendments call for periodic review and revision of the federal standards, which will maintain their link to the state of the science in toxicology and environmental health. Implementation of the NAAQS already issued for O₃ (8-hour) and PM_{2.5} will press areas including Louisville to strengthen existing control programs. New federal standards for diesel fuel sulfur content, gasoline sulfur content, highway vehicle emission controls, and non-road equipment emission controls should result in large reductions in mobile source SO₂, NO_x, particulates, and the related problems of tropospheric O₃, regional haze, and acid deposition. The latter set of federal controls will assist Louisville and other communities in meeting the former set of standards.

Federal regulation of air pollution from industries and utilities will likely change significantly over the next two years. The legislative and executive branches continue to debate a range of regulatory reforms that could recast the options available to companies to meet their air quality obligations. “Cap-and-trade” systems would relieve point sources of individual emission limits or requirements to install specific emission reduction devices. Instead, the government would allot a limited number of emission allowances each year to existing sources of a given pollutant. By reducing the annual allotment of allowances for a pollutant, EPA would reduce the nationwide total allowable emissions of that pollutant without dictating how to achieve the reductions. By permitting trading of the allowances, the government would intend to foster the most cost-effective means of reducing emissions. Multi-pollutant cap-and-trade strategies enable companies to reap additional financial rewards by taking measures that reduce two or more pollutants simultaneously. The multi-pollutant approach also frees companies from needing to install specific pollution control devices for each of several pollutants, with the result of high costs and greater-than-needed emissions reductions. Opponents cite two disadvantages of cap-and-trade systems: the flexibility they offer to continue running a profitable but dirty plant by purchasing additional allowances, thereby causing regional emissions hot spots; and the likelihood that a free market in emissions allowances will lead companies in aggregate to exactly meet the national emissions limits for the pollutants in question. In contrast, existing “technology-forcing” standards often lead to facility-by-facility emissions reductions well above those required by law. The Kyoto Protocol, not ratified by the US, has established an international trading system for CO₂ allowances. The US Congress and administration are contemplating mechanisms to allow voluntary trading of CO₂ allowances by US companies. The Bush administration currently opposes mandatory reductions of greenhouse gases.

The federal government also sponsors voluntary, incentive-based programs that can benefit air quality. Two areas of focus include reducing automotive travel demand and improving efficiency in the use of energy. EPA and the Federal Highway Administration provide technical assistance and some funding to communities exploring and using strategies to reduce suburban sprawl, encourage non-automotive transportation, and otherwise reduce private automobile use and its numerous environmental consequences. EPA’s growing Energy Star[®] program promotes energy-efficiency in appliances, office

equipment, buildings, and large institutions. US Department of Energy (DOE) runs or collaborates in a host of programs to increase energy-efficiency, especially in industry. The National Renewable Energy Laboratory of DOE promotes the development and application of low- and zero-emission energy resources. Through its national laboratories, DOE conducts research on advanced energy technologies and technologies to increase the energy-efficiency of buildings and industrial processes. In addition to reducing emissions of criteria pollutants and their contributions to acid deposition and regional haze, these programs provide avenues for enormous reductions in CO₂ emissions.

The federal government has also initiated work on practical means to mitigate the urban heat island effect. Many surfaces exposed to sunlight in urban areas have higher thermal mass (heat capacity) and solar absorbance than the corresponding surfaces in rural or undeveloped land. Black asphalt roofs and pavements exemplify urban surfaces that absorb and slowly release solar radiation. As a result, cities tend to reach higher summer temperatures than do their surrounding suburbs that, in turn, reach higher temperatures than the surrounding fields and forests. The heat island effect can cause urban peak temperatures 2 – 10 °F higher than in the surrounding countryside. Higher summertime temperatures harm urban air quality in at least four ways: 1) increasing the rate at which ground-level O₃ forms; 2) increasing energy demand for cooling buildings and motor vehicles, and thereby causing additional energy-related emissions; 3) increasing evaporative emissions of VOCs from motor vehicle fuel systems; and 4) increasing biogenic emissions of VOCs from trees. These effects can be large: a modest heat island effect of 3 °F may increase Louisville's peak O₃ levels by 5-10%. Lawrence Berkeley National Laboratory (LBNL) and National Aeronautics and Space Administration are engaged in research to characterize the heat islands of several US cities and the air quality implications of those heat islands. LBNL researchers also develop and test materials and methods to reduce the heat island effect. EPA disseminates information, promotes actions to mitigate the heat island effect, and provides technical assistance to municipal officials developing local heat island policies and programs.

Local Initiatives

Greater Louisville has many options for improving its air quality beyond the improvements promised by forthcoming federal standards. Four promising areas are: reducing transportation-related emissions; reducing energy-related emissions; reducing point source and area source emissions through pollution prevention; and taming the urban heat island. Successful work in any of these areas will cause declines in more than one pollutant.

Reducing Transportation-Related Emissions

Transportation-related emissions can be reduced by cutting emissions per mile or by reducing the vehicle-miles of travel (VMT) in the region. Local reductions in emissions per mile can come from:

- encouraging the use of low-emission vehicles;

- improving the efficiency of the road network, to allow motor vehicles to operate more consistently within the ranges of speeds and accelerations that yield lowest emissions;
- mandating local use of fuels that provide lower emissions; and
- repairing or retiring from service motor vehicles that do not meet modern emission standards.

The second and third of these options already have found use in Jefferson County, in the form of downtown streets with synchronized traffic signals and the local requirement to sell only reformulated oxygenated gasoline. The fourth option comprises part of the vehicle emissions test improvement proposal announced in January 2002 by Judge Executive Rebecca Jackson. Refinement, extension, and further application of these four general strategies will build on the emissions reductions achieved to date.

Several approaches may help to reduce VMT. They fall into two general categories:

- reducing travel demand; and
- encouraging shifts to other travel modes from private automobile use.

Travel demand relates strongly to land use patterns. Segregation of land uses (e.g., commercial, residential, industrial) increases average distances from home to work and other destinations. Trends away from multi-family housing and toward larger lots for single-family homes increase the diameter of the urban area for any given population. Residential subdivisions with relatively large lots, no sidewalks, and no focal point for spontaneous social interaction (e.g., a neighborhood park) increase the need to travel elsewhere for recreation. Regional and community form exert a strong influence on travel demand.

Regional and community form also influence the viability of non-automotive travel modes. Decreases in population density result in fewer people living within walking distance of any given transit stop. Coupled with longer average trip distances, this increases transit operating costs while decreasing fare revenue per mile. Bicycling and walking also become less attractive as distances from origin to destination expand.

Through the Cornerstone 2020 comprehensive plan, Jefferson County is taking steps toward community design that would allow citizens to meet more of their needs closer to home. Encouraging a mixture of residential and commercial uses in a compact area may lead to more opportunities for people to live close to places where they work, shop, and enjoy pastimes. Increased urban redevelopment and creation of suburban neighborhoods that include parks and pedestrian and bicycle connections to nearby activity centers may similarly reduce automotive travel demand.

Programs to encourage car-pooling, transit use, telecommuting, bicycling, and walking can reduce the demand for motor vehicle travel. The success of such programs relies on presenting the traveler with a choice that compares favorably with driving. Costs in time and money, and benefits in flexibility, safety, comfort, enjoyment, and health, will factor into each individual's travel choice. As long as the costs of roads, traffic enforcement,

accidents, pollution, and noise remain separate from an individual's perceived costs of driving, people will have far less incentive to shift to more cost-effective and environmentally benign travel modes.

Reducing Energy-Related Emissions

Fostering energy efficiency offers direct economic benefits as well as emission reductions. Locally, increased education and technical support can increase adoption of cost-effective energy conservation measures. Residences, businesses, and institutions all offer large potential energy savings. Industrial managers often reject energy-saving changes in manufacturing processes to avoid the possibility of disruptions to production or product quality. A change that saves energy but increases downtime, for example, will rarely earn management approval. Careful scrutiny will often reveal measures that will raise energy efficiency while also improving the productivity, reliability, or safety of the process.

Local government can encourage energy efficiency by a variety of means. Promising options include:

- providing technical support and training to architects and builders, residents, business owners, and factory managers;
- operating or promoting an energy rating system for buildings, to guide buyers of homes and businesses;
- improving the energy efficiency of municipally-owned facilities and setting high standards for the energy efficiency of new facilities; and
- encouraging homeowners to plant shade trees on the east or west sides of their homes.

Combined heat and power (CHP or "cogeneration") provides on-site generation of electricity and heat for a facility that needs both. Using the byproduct heat from electrical generation raises overall fuel efficiency from about 35% to 70% or more. CHP using natural gas-fired microturbine, fuel cell, or other clean generating method can provide electricity and heat with low emissions. CHP may play an important role in reducing CO₂ emissions and criteria pollutant emissions from coal-fired power plants. It has its greatest potential in commercial, industrial, and multi-family residential sites.

Low- and zero-emission sources of heat and electricity will increasingly play a role in reducing the need to burn carbon-based fuels. Jefferson County receives enough sunlight to make good use of solar energy for space heating and water heating. Current generation costs of solar electricity make it economically unattractive for most applications in Jefferson County. Average wind speeds in the area generally do not allow for cost-effective wind-generated electricity. The primary renewable sources of electricity in the region will remain refuse-derived and biomass-derived fuels (e.g., landfill gas and biodiesel refined from used cooking oil) and hydroelectric power. Capital improvements at the Louisville Gas and Electric Company Ohio Falls Hydroelectric Station could boost that plant's peak capacity from 80 MW to about 100 MW.

Mitigating the Urban Heat Island Effect

Four main tools exist for reducing the urban heat island effect: urban forestry, land use planning, cool roofing materials, and cool paving materials. Trees anywhere within the urban area will reduce air temperature by evaporation of moisture from their leaves. They also shade more absorptive and heat-retaining surfaces. When placed close to houses and other buildings (preferably not on the south side where they will block desirable winter solar heat gain), trees provide additional cooling season energy savings. Compact land development patterns reduce overall paved area and leave more land for green space including forests. Studies show that reducing suburban sprawl and increase tree canopy coverage have the largest potential effect on a city's heat island. White elastomeric roof membranes and some elastomeric roof coatings offer high albedo (solar reflectance) and high infrared emissivity (tendency to re-emit heat to the sky), so they absorb little solar energy and readily re-radiate it. Incentives to reduce the initial cost of these roofing materials, in conjunction with promotional campaigns to improve their acceptance on visible rooftops, could speed the adoption of this technology. Light-colored pavement materials, including blended cement concretes made with fly ash or blast furnace slags, can offer excellent durability and relatively high albedo. For light-duty parking areas, grass-filled or gravel-filled pervious paving systems can replace asphalt with a significant reduction in heat absorption. Pavement substitutions offer slightly less overall heat island reduction potential than do roofing material substitutions.

Pollution Prevention

Great advances in environmental protection can come from the redesign of industrial and commercial processes to eliminate harmful effluents rather than installing pollution control devices to capture and treat effluents from less elegant processes. In manufacturing, this can take the form of designing a facility so the effluent of one process becomes a feedstock for another, with the final process in the chain producing no noxious substances. Sometimes, adding a mechanical process can obviate a chemical process with an undesirable waste product. Households and small businesses as well as large industries can replace solvent-based coatings and cleaners with water-based substitutes in increasingly many cases. Public education and technology transfer constitute the key means to encourage pollution prevention.

Challenges to Improving Regional Air Quality

Government, business, and citizens at large will need to cooperate to achieve further improvements in regional air quality. Some potential challenges include:

- continuing growth in VMT and trend toward heavier vehicles, increasing CO₂ emissions even with projected advances in motor vehicle emissions controls and fuels;
- continuing growth in developed land area, exacerbating the urban heat island effect, fueling continued VMT growth, and probably increasing fugitive dust emissions;

- continued growth in per capita living space, increasing energy demand and the urban heat island effect, and hence urban O₃ levels;
- continued reliance on coal as the primary fuel for electrical generation, producing large CO₂ emissions and contributing to acid rain, regional haze, and ground-level O₃;
- further delays in the implementation of new federal standards for mobile source fuels and emissions controls; and
- adverse economic conditions, reducing the availability of capital to invest in industrial pollution prevention and energy efficiency measures.

Peering into the Crystal Ball: Louisville's Air Quality, 2020

With continued public support, public officials will continue to work in 2020 to improve environmental quality. Environmental non-governmental organizations, businesses, and private individuals will collaborate with government agencies to define necessary standards of environmental quality and find ways to meet those standards. By 2020 the current criteria air pollutants will probably have minimal significance, particularly if acid deposition and haze have declined to acceptable levels. Air toxics (perhaps with some important modifications to the current list) will probably require ongoing scrutiny and reduction. Greenhouse gases may pose the most urgent challenge. Given the complexities of atmospheric chemistry and epidemiology, the science and practice of air pollution control will evolve for decades to come. Some current practices will prove highly effective. Others will probably prove less so, due to gaps in current understanding. Improvements from 1970 – 2001 provide confidence, though, that pollution control efforts to date have improved public health and protected natural resources while preserving economic vitality.

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